論文の内容の要旨

Hafnium-tungsten chronology and geochemistry of pallasites

(パラサイト隕石のハフニウム-タングステン年代学および地球化学的研究)

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Constraining the formation process of planetesimals is the crucial problem to understand the solar system evolution. Planetesimals play a role as seeds of planetary embryos and planets, though how and how long it takes to accrete planetesimals are still unclear due to several theoretical problems, such as the radial drift barrier and the fragmentation barrier. Therefore, constraining these parameters from an aspect of material science is significant to unravel the solar system evolution since materials we can obtain nowadays are results of the variable process during the solar system evolution.

Meteorites are the most abundant and accessible among various extraterrestrial materials. Moreover, meteorites exhibit a vast range of physical, petrological, and chemical properties, providing a powerful means to investigate the nature and evolution of their parent bodies and the solar system. Undifferentiated meteorites are likely to represent undifferentiated planetesimals, thus materials condensed from the protoplanetary disks. On the other hand, differentiated meteorites represent more evolved planetesimals, including the Earth, the Moon, and the Mars. The constraint on the parent body of differentiated meteorites will provide the conditions for planetesimals to differentiate.

Pallasite meteorites are one group of differentiated meteorites. These unique meteorites are composed of roughly equivalent amounts of olivine and FeNi metal. Since olivine and FeNi metal are thought to be the major component of a mantle and core of a fully differentiated chondritic body, pallasites are expected to possess the information of both planetary mantle and core. The slow cooling rate recorded in FeNi metal, diffusion pattern implying slow cooling recorded in olivine, and various isotopic links with IIIAB iron meteorites, which regarded as representative of a planetary core, suggest pallasite represent the core-mantle boundary of its parent body. Therefore, pallasites are suitable species in understanding the evolution of the planetary interior.

Despite their high importance in exploring the early planetary evolution, how pallasites formed are unresolved. Based on the cooling rate determined on pallasites, the size of the pallasite parent body was estimated as 200 – 400 km. The predicted size conflict with the vast difference in density of olivine and FeNi metal, who should be separated by buoyancy at the core-mantle boundary on such a large planetesimal. To explain the mixing mechanism, several models were proposed, such as convection during the fractional crystallization or impact mixing of core and mantle material. Though these models partially fulfill the pallasite features, whole understanding is not have made.

The size estimates of the pallasite parent body are based on a simple planetary cooling model. Insufficient explanation of pallasite formation mechanisms may be due to depending on the size estimation with ignores the heat production from radioactive decay of extinct nuclides. As determined by the Al-Mg dating on pallasite olivine, the pallasite parent body is suggested to have accreted within 2 Myr from the CAI formation. In such a case, heat production from ^{26}Al and ^{60}Fe may play a critical role in planetary evolution. In addition, if olivine and FeNi are mixed later the core-mantle segregation, these two phases should have different thermal and age records. Therefore extracting the formation age and thermal history from two major phases of pallasites is necessary to understand the pallasite formation mechanism.

The purpose of this study is to complement the insufficient chronological and thermal record of pallasites to reassess the history of the pallasite parent body and giving constraint on conditions of planetesimals to differentiate.

In Chapter 2, we applied the ^{182}Hf-^{182}W dating on FeNi metal in pallasites. Since W isotopes would fluctuate not only by decay of ^{182}Hf but also by the nucleosynthetic anomaly in the solar nebula and the neutron capture effect due to the irradiation of cosmic rays. Therefore, we evaluated the nucleosynthetic anomaly and the neutron capture effect by measuring ^{183}W/^{184}W and ^{196}Pt/^{195}Pt values. From the ^{183}W/^{184}W ratio, the nucleosynthetic anomaly was not observed in pallasites, indicating the pallasite parent body accreted in the inner solar system. From Pt isotopic measurement, we detected the neutron capture effect of pallasites. The corrected ^{182}W/^{184}W value corresponds to the Hf-W age of 0.08 ± 1.08 Myr after the CAI formation, suggesting the pallasite parent body accreted and differentiated within 1.2 Myr from the solar system evolution.

In Chapter 3, we determined the cooling rate of chromite and olivine in pallasites. From mineralogical observation done on Sericho meteorite, we confirmed neighboring chromite and olivine were reacting under subsolidus and exchanging Fe^{2+} and Mg. We applied the olivine-spinel geospeedometer on this chromite, obtaining the prolonged cooling rate of 10-30 K/Myr, which coincident with the metallographic cooling rate of FeNi metal in pallasites.

In Chapter 4, the new thermal evolution model of the pallasite parent body was calculated using the data obtained in this study. By considering the thermal production from ^{26}Al and ^{60}Fe, we found that radionuclides comfort the cooling rate of the planet with 20 km in radius. On the other hand, the planet larger than 50 km in radius has little effect of radionuclides due to prolonged cooling time related to its size. Though the cooling rate obtained by the olivine-spinel geospeedometer could be accomplished with the core-mantle boundary of the 75 km sized planet. The estimated parent body size implies that planetesimals smaller than 100 km in radius would accrete and fully differentiate to make the core and mantle within 1.2 Myr after the CAI formation.